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MEASUREMENT AND ANALYSIS OF ATMOSPHERIC SPECTRAL OPTICAL DEPTHS WITH NASA AMES AIRBORNE SUNPHOTOMETERS DURING TARFOX AND ACE-2

John M. Livingston, Senior Research Meteorologist
Geoscience and Engineering Center

SRI Project 7325

Prepared for:

NASA Ames Research Center
Philip B. Russell, Technical Contract Monitor
M/S: 245-5
P.O. Box 1000
Moffett Field, California 94035-1000

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Approved:

Elizabeth J. Brackmann, Co-Director
Geoscience and Engineering Center

1 INTRODUCTION

This is an interim technical report covering the period 1 January 1996 through 30 September 1996 for the NASA Ames Research Center Cooperative Agreement NCC 2-938 with SRI International. It is submitted as a substitute for a performance report for the same time period.

2 TECHNICAL SUMMARY

Two NASA Ames automatic tracking airborne sunphotometers were used during the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX) in July 1996 to acquire spectral solar irradiance measurements. The Ames six-channel sunphotometer was operated on board the University of Washington C-131A aircraft and acquired data during eighteen flights (July 10-31) that varied in duration from two to six hours. A new Ames fourteen-channel sunphotometer was flown aboard the Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS) Pelican (modified Cessna), and acquired data during a limited number of flights during the final five days of TARFOX. Selected data sets from each instrument have been analyzed to derive preliminary estimates of atmospheric total and particulate spectral optical depth. These data are presented below.

Prior to TARFOX, the six-channel sunphotometer was operated from the ground at Mauna Loa Observatory during the mornings of 21-26 May. These measurements were analyzed using the Langley plot technique to estimate the most probable exoatmospheric, or zero-airmass intercept, voltages in the 380, 451, 525, 864, and 1020-nm wavelength channels. Corresponding values have not yet been calculated for the 941-nm channel data because solar irradiance measured in that passband requires a more sophisticated analysis procedure due to strong water vapor absorption, which does not follow Beer's Law. Table 1 presents a statistical summary of the intercept voltages derived from the Mauna Loa measurements. These intercept voltages were used during TARFOX to calculate real-time aerosol optical depths, and have been used subsequently for analyses of the data collected during TARFOX. Figure 1(a) shows a typical plot of detector output voltage as a function of time for a Mauna Loa sunrise event (23 May), and Figure 1(b) shows the corresponding plot of detector output as a function of airmass for all channels except 941 nm. Mean aerosol optical depths and uncertainties are presented in Figure 1(c) for the time period (6:26 - 8:27 HST) corresponding to the range of airmass values (6.5 - 1.7) used to derive intercept voltages for measurements acquired on 23 May. The mean intercept voltages listed in Table 1 were used to calculate total optical depths. The aerosol optical depths were then derived from the inferred total optical depths by subtracting optical depth contributions ozone absorption (calculated from the ozone column content measured daily at Mauna Loa by a NOAA Dobson spectrophotometer), and nitrogen dioxide absorption (calculated using an assumed column content of 5 x 10^{15} molecules/cm^2). The aerosol optical depths shown for the May 23rd measurements are typical of those calculated for Mauna Loa during the calibration time period. They are quite low and reflect the return to background stratospheric aerosol optical depths following a prolonged period of enhanced stratospheric aerosol caused by the 1991 eruption of Mount Pinatubo. Because Mauna Loa Observatory is located at an altitude of 3.4 km, which is well below the tropopause height at that location, the measured values include both stratospheric and free tropospheric aerosol optical depth components.

Representative multi-wavelength aerosol optical depths calculated from data taken during TARFOX with the six-channel sunphotometer are presented in Figure 2(a,b). Figure 2(a) shows the values calculated along a latitudinal transect across a large gradient in aerosol optical depth. Measurements were taken at an aircraft altitude approximately 100 ft above the Atlantic Ocean surface. Aerosol optical depths are not shown for the 864-nm channel, because that channel malfunctioned during TARFOX. Transects like that shown in Figure 2(a) will be used in subsequent TARFOX analyses to test optical depth retrievals made by satellite, and to provide inputs to a variety of calculations of radiative effects and physical/optical/chemical closure analyses. In Figure 2(b), a vertical profile of aerosol optical depth is shown for measurements obtained during the aircraft ascent above point H (the location of the maximum aerosol optical depth along the transect). These optical depth spectra can be differentiated to yield vertical profiles or layer averages of extinction coefficient, which can then be compared to those calculated from *in-situ* particle size, shape, and composition measurements, or to those measured by *in-situ* nephelometry and aethalometry. Such analyses are planned.

The new Ames fourteen-channel airborne sunphotometer was still in development at Ames during the pre-TARFOX May calibration at Mauna Loa, and was not available for calibration. In fact, the first mountaintop calibration of this instrument is scheduled to take place in Germany during a joint United States-Europe radiometer intercalibration experiment to be held in Germany in mid-October of this year in preparation for the second Aerosol Characterization Experiment (ACE-2) that will take place off the coast of Spain in summer 1997. Hence, no intercept voltages were available for the new sunphotometer during TARFOX. Following TARFOX, however, intercept voltages were estimated from simultaneous measurements taken from a rooftop at NASA Ames on 27 August with both NASA airborne instruments. Intercept voltages were derived for the fourteen-channel instrument by requiring the aerosol optical depths calculated from its data to equal the corresponding values derived from data obtained in nearly wavelength-coincident channels of the six-channel instrument (for which the intercept values are well-known from the May Mauna Loa data). Figure 3(a) presents optical depth spectra derived from the 27 August sunphotometer intercomparison, and Figure 3(b,c) shows spectra calculated by applying the estimated intercept voltages to TARFOX measurements obtained with the fourteen-channel instrument.

TABLE 1

ZERO-AIRMASS VOLTAGE INTERCEPT VALUES FOR THE SIX-CHANNEL AMES AIRBORNE AUTOTRACKING SUNPHOTOMETER (AAAS)

DATE	CENTER WAVELENGTH (nm) 380.1	450.7	525.3	862.0 / 863.9*	1020.7
April 1994[A1]	6.219 ± 0.3%	5.290 ± 0.7%	7.984 ± 0.7%	7.924 ± 0.8%	7.027 ± 0.8%
November 1994[H1]	5.888 ± 0.5%	5.235 ± 0.4%	7.900 ± 0.3%	7.945 ± 0.7%	7.018 ± 0.8%
October 1995[A2]	5.663 ± 0.5%	5.137 ± 0.5%	7.751 ± 0.2%	8.225 ± 0.3%	7.004 ± 0.3%
May 1996[H2]	5.553 ± 0.5%	5.210 ± 0.2%	7.671 ± 0.3%	*6.675 ± 0.1%	6.962 ± 0.4%

[A1] Mt. Lemmon Steward Observatory, Tucson, Arizona. Includes data from three days: 25, 28, 29 April.
[H1] Mauna Loa Observatory, Hawaii. Includes data from seven days: 3, 6, 7, 8, 9, 14, 19 November.
[A2] Mt. Lemmon Steward Observatory, Tucson, Arizona. Includes data from five days: 17-21 October 1995.
[H2] Mauna Loa Observatory, Hawaii. Includes data from five days: 21-25 May.

TABLE 2

AAAS INTERCEPT VALUES DURING THE MAUNA LOA MAY 1996 MEASUREMENT PERIOD

DATE	CENTER WAVELENGTH (nm) 380.1	450.7	525.3	863.9	1020.7	airmass range
21 May	5.5605	5.2165	7.6854	6.6778	6.9356	1.7 - 6.5
22 May	5.5044	5.1914	7.6647	6.6793	6.9901	1.7 - 6.5
23 May	5.5593	5.2187	7.6959	6.6792	6.9999	1.7 - 6.5
24 May	5.5752	5.2162	7.6362	6.6672	6.9372	1.7 - 6.5
25 May	5.5669	5.2069	7.6710	6.6705	6.9499	2.15 - 6.5
26 May	5.5504	5.2167	7.6817	6.7072	6.9803	1.7 - 6.5
Mean,sd (all):	5.5528± 0.45%	5.2111 ± 0.20%	7.6725 ± 0.27%	6.6802 ± 0.21%	6.9655 ± 0.40%	
Mean,sd (omit 5/26):	5.5533± 0.50%	5.2099 ± 0.22%	7.6706 ± 0.30%	6.6748 ± 0.08%	6.9625 ± 0.44%	

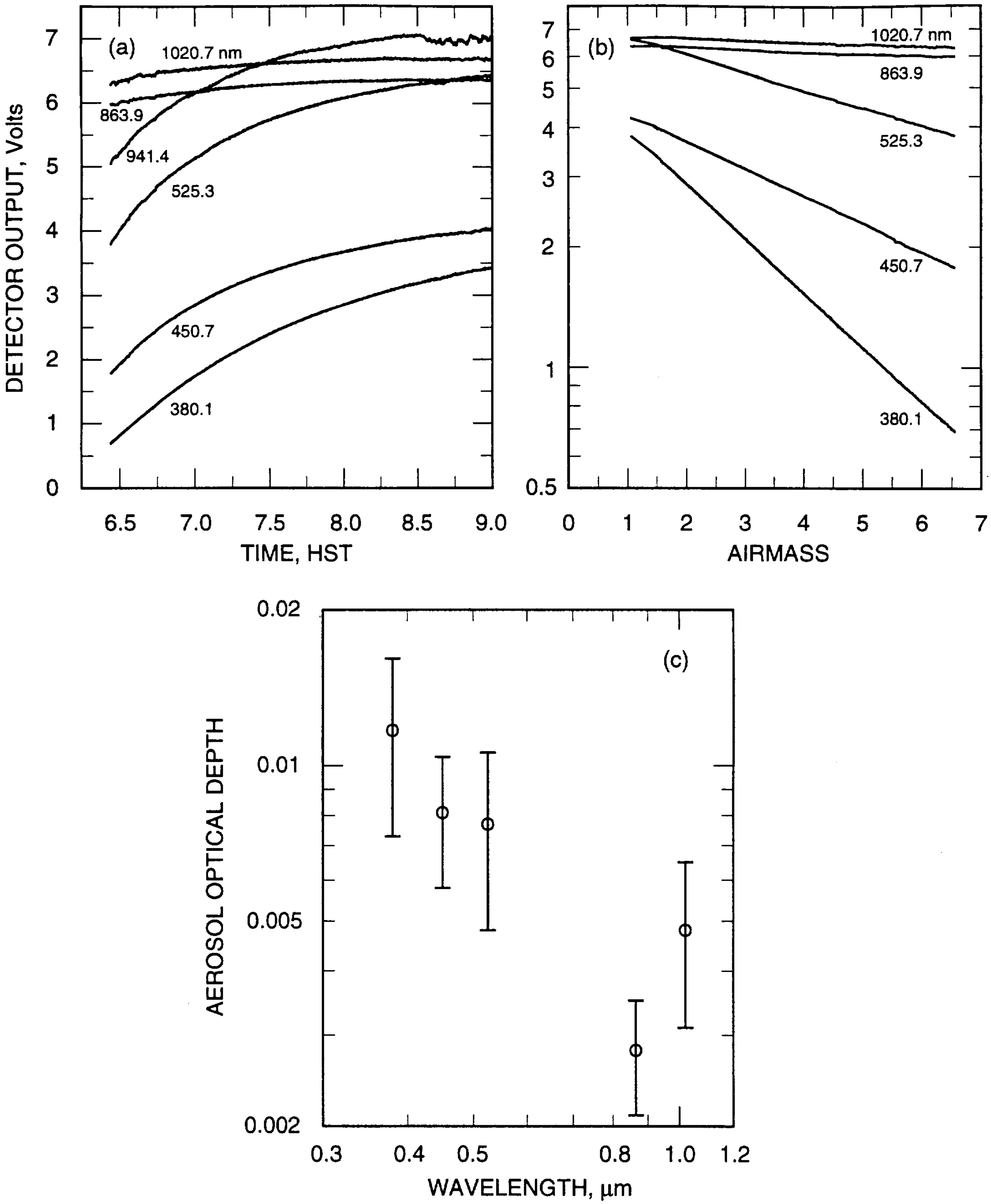

FIGURE 1 Measurements taken at Mauna Loa Observatory on 23 May 1996 with the NASA Ames six-channel airborne sunphotometer. (a) Detector output as a function of time, (b) detector output as a function of airmass, and (c) mean aerosol optical depths and uncertainties as a function of wavelength for the time period 6:26 - 8:27 local time (airmass values of 1.7 - 6.5).

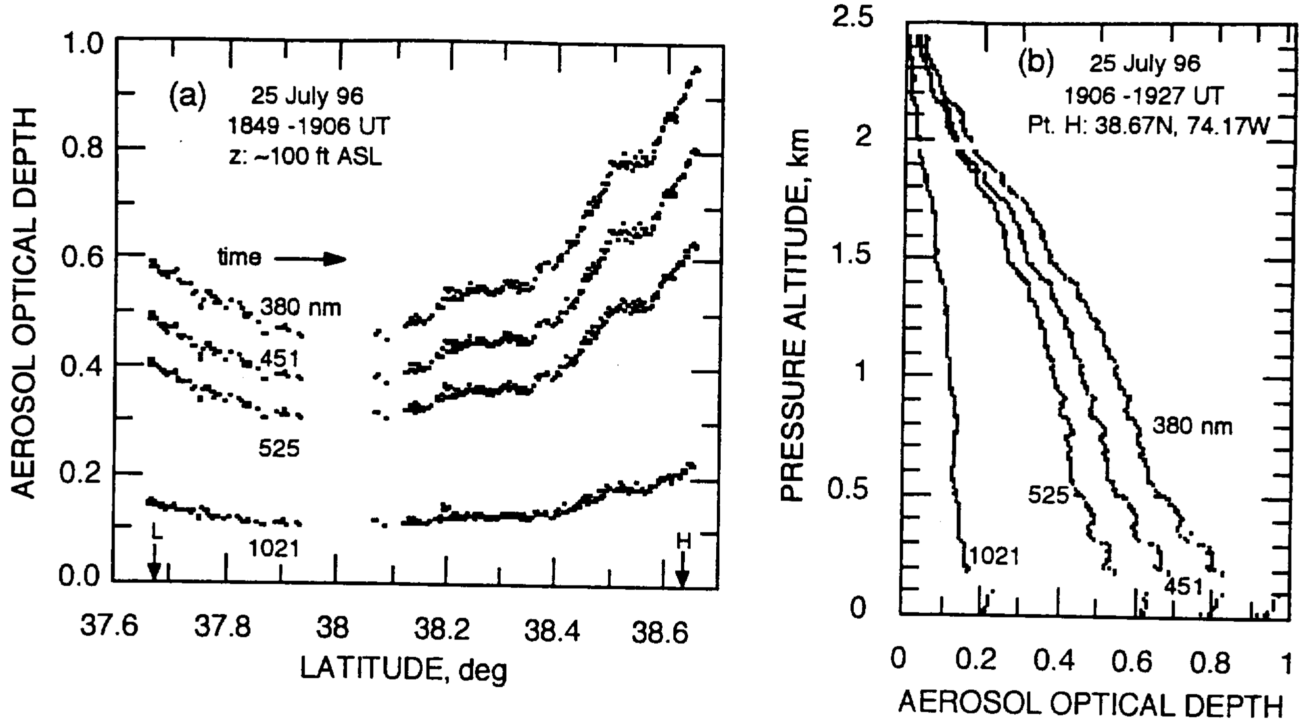

FIGURE 2 Aerosol optical depths (λ = 380, 451, 525, 1021 nm) measured by the Ames 6-channel tracking sunphotometer on the UW C-131A in TARFOX. (a) Latitude transect. (b) Vertical profile.

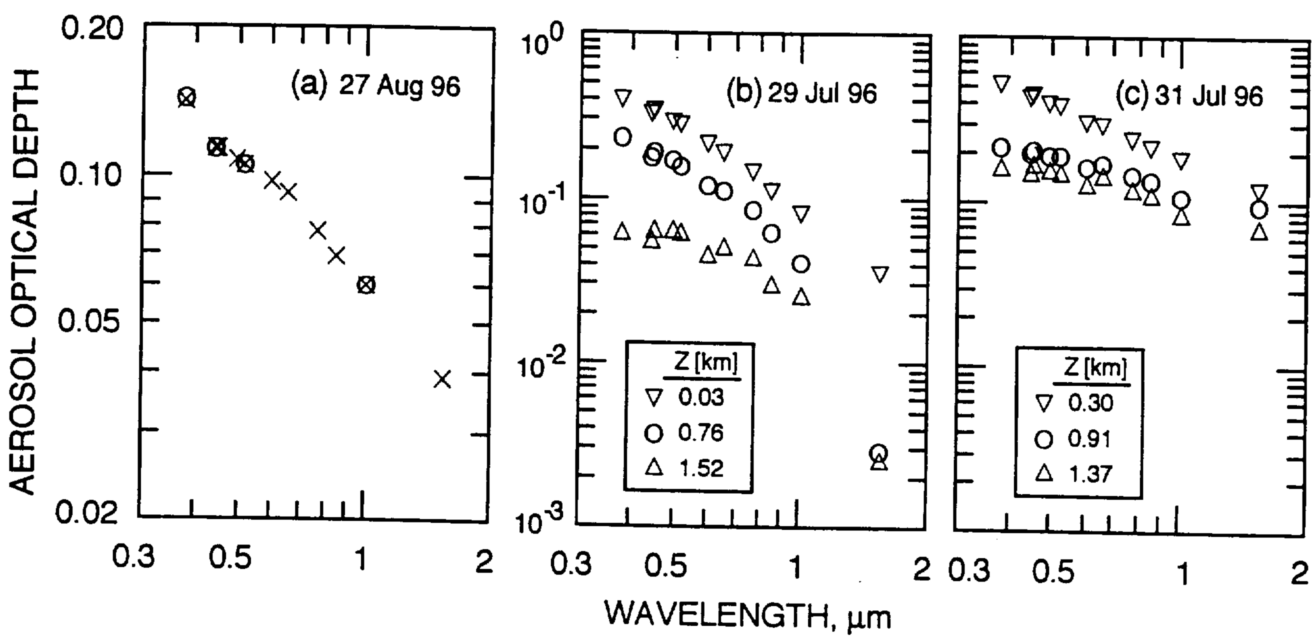

FIGURE 3 (a) Aerosol optical depth spectra measured by the 6-channel (O) and 14-channel (X) tracking sunphotometers at NASA Ames. (b, c) Aerosol optical depth spectra measured by the 14-channel sunphotometer on the Pelican aircraft in TARFOX over and off the coast of Virginia/Maryland/Delaware. All spectra for the 14-channel instrument use a single, approximate calibration derived from a comparison to the 6-channel instrument conducted on 27 August 1996.